METHOD AND SYSTEM FOR EXTRACTION OF RESOURCES FROM A SUBTERRANEAN WELL BORE

TECHNICAL FIELD OF THE INVENTION

The present invention relates generally to recovery of subterranean resources and more particularly to a method and system extraction of resources from a subterranean well bore.

BACKGROUND OF THE INVENTION

Subterranean deposits of coal, also referred to as coal beds, contain substantial quantities of entrained resources, such as natural gas (including methane gas or any other naturally occurring gases). Production and use of natural gas from coal deposits has occurred for many years. However, substantial obstacles have frustrated more extensive development and use of natural gas deposits in coal beds.

SUMMARY OF THE INVENTION

According to one embodiment of the invention, a method for extracting resources from a subterranean coal bed is provided. The method includes forming a drainage well bore in the coal bed. The well bore has a first end at a ground surface and a second end in the coal bed. The method also includes inserting a tube into the second end of the drainage well bore. The method also includes generating a flow of fluid from the second end to the first end by injecting fluid into the second end through the tube. The method also includes collecting, at the first end, a mixture comprising the fluid, a plurality of coal fines, and any resource from the well bore that is mixed with the fluid.

According to another embodiment, a method for stimulating production of resources from a coal seam includes forming a drainage well bore in the coal bed that has a first end coupled to a ground surface and a second end in the coal bed. The method further includes inserting a liner into the well bore. The liner has a wall including a number of apertures and a second diameter that is smaller than the first diameter of the drainage well bore such that a gap is formed between the wall of the liner and the well bore. The method also includes collapsing the drainage well bore around the liner to relieve stress in the coal seam proximate to the liner.

Some embodiments of the invention provide numerous technical advantages. Some embodiments may benefit from some, none, or all of these advantages. For example, according to certain embodiments, resource production

from a well bore is improved by an efficient removal of water and obstructive material. In particular embodiments, such water and obstructive material may be moved without the use of a down hole pump.

Furthermore, in certain embodiments, efficiency of gas production may be improved in a coal beds by increasing the permeability of parts of the coal by providing controlled collapse of a portion of the coal or other forms of stress relief in portions of the coal. Such stress relief may be particularly useful in low permeability, high gas content coal beds and can stimulate production in such coal beds. In addition, in particular embodiments, a drainage well bore having a flatter curvature may be used to efficiently produce resources by angling the drainage well bore downward relative to the horizontal in the coal seam.

Other technical advantages will be readily apparent to one skilled in the art.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is now made to the following description taken in conjunction with the accompanying drawings, wherein like reference numbers represent like parts, in which:

FIGURE 1 is a schematic diagram illustrating one embodiment of a resource extraction system constructed in accordance with one embodiment of the present invention;

FIGURE 2A is a cross sectional diagram illustrating one embodiment of a liner and a tube in a well bore shown in FIGURE 1;

FIGURE 2B is a cross sectional diagram illustrating one embodiment of the liner and the tube positioned in the well bore of FIGURE 2A after a collapse of the well bore; and

FIGURE 3 is a flow chart illustrating one embodiment of a method for extraction of resources from the well bore of FIGURE 1.

DETAILED DESCRIPTION

Embodiments of the invention are best understood by referring to FIGURES 1 through 3 of the drawings, like numerals being used for like and corresponding parts of the various drawings.

FIGURE 1 is a schematic diagram illustrating one embodiment of a well system 10. Well system 10 includes a resource extraction system 12 positioned on a ground surface 36 and a drainage well bore 14 that extends below ground surface 36. Drainage well bore 14 includes an open end 16, a substantially vertical portion 18, an articulated potion 20, and a drainage portion 22. Any one of portions 18, 20, and 22 of well bore 14 may individually constitute a well bore, and may be referred to as a well bore herein. Drainage portion 22 of well bore 14 includes a first end 24 and a second end 28. As shown in FIGURE 1, first end 24 of drainage portion 22 is accessible from a location above ground surface 36, such as open end 16. In one embodiment, second end 28 of drainage portion 22 may be a closed end that is not accessible from a location above ground surface, except through first end 24 of drainage portion 22, as shown in FIGURE 1. As used herein, second end 28 is also referred to as a closed end 28. Second end 28 also constitutes an end 28 of drainage well bore 14. Drainage portion 22 of well bore 14 may be positioned at least partly in a coal bed 30 or any other appropriate subterranean zone that includes resources to be extracted.

Drainage well bore 14 may be drilled using an articulated drill string that includes a suitable down hole motor and a drill bit. A measurement while drilling

("MWD") device may be included in articulated drill string for controlling the orientation and direction of the well bore drilled by the motor and the drill bit.

As shown in FIGURE 1, drainage portion 22 is approximately horizontal. In one embodiment where ground surface 36 is substantially horizontal, a distance 34 from ground surface 36 to end 24 is approximately equal to a distance 38 between ground surface 36 and end 28. However, portion 22 is not required to be horizontal. For example, where well bore 14 is a down-dip or an up-dip well bore, portion 22 may be sloped. In a down-dip configuration, distance 38 may be greater than distance 34, which allows articulated portion 20 to be less curved. This is advantageous because a less extreme curvature at portion 20 allows the overall length of well bore 14 to be greater, which improves efficiency of resource production. Because a flow of fluid is generated from end 28 of portion 22 to move the gas in portion 22 to ground surface 36, production inefficiencies conventionally associated with a down-dip well bore is reduced. In one embodiment, drainage portion 22 may be approximately horizontal with respect to coal bed 30, regardless of whether coal bed 30 is parallel to ground surface 36. In one embodiment, portion 22 may be angled with respect to coal bed 30 rather than ground surface 36.

Production of resources, such as natural gas, may be dependent on the level of resource content in coal bed 30 and permeability of coal bed 30. Gas is used herein as an example resource available from a coal region, such as coal bed 30; however, the teachings of the present

invention may be applicable to any resource available from a subterranean zone that may be extracted using a well bore. In general, less restricted movement of gas within coal bed 30 allows more gas to move into well bore 14, which allows more gas to be removed from well bore 14. Thus, a coal bed having low permeability often results in inefficient resource production because the low number and/or low width of the cleats in coal bed 30 limit the movement of gas into well bore 14. In contrast, high permeability results in a more efficient resource production because the higher number of pores allow freer movement of gas into well bore 14.

Conventionally, a well bore is drilled to reach a coal bed that includes resources, such as natural gas. Once a well bore is formed, a mixture of resources, water, and coal fines may be forced out of the coal bed through the well bore because of the pressure difference between the ground surface and the coal bed. After collecting the mixture at the ground surface, the resource is separated from the mixture. However, production of resources from a well bore in such a manner may be inefficient for numerous reasons. For example, the level of resource production may be reduced due to the coal fines that may obstruct the well bore or a possible collapse of the well bore. A well bore in a coal bed having low permeability or under lower pressure may produce a lower level of resources. Additionally, a "down dip" well bore, which refers to an articulated well bore having a flatter curvature and a portion that slopes downward from the horizontal, may produce a lower level of resources due to a higher producing bottom hole

pressure resulting from the hydrostatic pressure of the water collecting up to the pumping point.

According to some embodiments of the present invention, a method and a system for extracting resources from a subterranean well bore are provided. In certain embodiments, efficiency of gas production may be improved in a coal beds by increasing the permeability of parts of the coal by providing controlled collapse of a portion of the coal or other forms of stress relief in portions of the coal. Such stress relief may be particularly useful in low permeability, high gas content coal beds and can stimulate production in such coal beds. In particular embodiments, a drainage well bore having a flatter curvature may be used to efficiently produce resources. Additional details of example embodiments of the methods and the systems are provided below in conjunction with FIGURES 1 through 3.

Referring back to FIGURE 1, resource extraction system 12 is provided for gas production from drainage well bore 14. System 12 includes a liner 44, a tube 58, a fluid injector 70 (which may inject gas, liquid, or foam), a well head housing 68, and a separator 74. Liner 44 has a first end 48 and a second end 50. Tube 58 has an entry end 60 and an exit end 64. Fluid injector 70 is coupled to entry end 60 of tube 58 through outlet 68. Housing 72 is coupled to separator 74 and is operable to direct any material from well bore 14 into separator 74. Separator 74 is coupled to fluid injector 70 through a pipe 94.

Fluid injector 70 is operable to urge an injection fluid out through outlet 68. An example of fluid

injector 70 is a pump or a compressor. Any suitable type of injection fluid may be used in conjunction with fluid injector 70. Examples of injection fluid may include the following: (1) production gas, such as natural gas, (2) water, (3) air, and (4) any combination of production gas, water, air and/or treating foam. In particular embodiments, production gas, water, air, or any combination of these may be provided from an outside source through a tube 71. In other embodiments, gas received from well bore 14 at separator 74 may be provided to injector 70 through tubes 90 and 94 for use as an injection fluid. In another embodiment, water received from well bore 14 at separator 74 may be provided to injector 70 through tubes 75 and 94 for use as an injection fluid. Thus, the fluid may be provided to injector 70 from an outside source and/or separator 74 that may recirculate fluid back to injector 70.

Separator 74 is operable to separate the gas, the water, and the particles and lets them be dealt with separately. Although the term "separation" is used, it should be understood that complete separation may not occur. For example, "separated" water may still include a small amount of particles. Once separated, the produced gas may be removed via outlet 90 for further treatment (if appropriate). In one embodiment, a portion of the produced gas may be provided to injector 70 via tube 94 for injection back into well bore 14. The particles, such as coal fines, may be removed for disposal via an outlet 77 and the water may be removed via an outlet 75. Although a single separator 74 is shown, the gas may be separated from the water in one

apparatus and the particles may be separated from the water in another apparatus. Furthermore, although a separation tank is shown, one skilled in the art will appreciate numerous different separation devices may be used and are encompassed within the scope of the present invention.

As shown as FIGURE 1, in particular embodiments, second end 50 of liner 44 is located approximately at closed end 28 of well bore 14. End 48 of liner 44 is approximately at opening 16 of well bore 14; however, end 48 may be anywhere along vertical portion 18 or articulated portion 20 of well bore 14. In certain embodiments, liner 44 may be omitted. In particular embodiments, the wall of liner 44 may include a plurality of apertures 54. Apertures 54 may include holes, slots, or openings of any other shape. In particular embodiments, the use of holes as the apertures may allow production of more coal fines than the use of slots, while the use of slots may provide more alignment of the apertures with cleats in the coal than when using holes. Although apertures in a portion of the liner 44 are illustrated, apertures may be included in any appropriate portion of the length of liner 44. The size of apertures 54 may be adjusted depending on the size of coal particles or other solids that are desired to be kept outside of liner 44. For example, if it is determined that a piece of coal having a diameter greater than one inch should not be inside liner 44, then each aperture 54 may have a diameter of less than one inch. In particular example embodiments, apertures 54 may be holes having a diameter of between 1/16 and 1.5 inches or slots having a

width of between 1/32 and 1/2 inches (although any other appropriate diameter or width may be used).

Tube 58 is positioned inside well bore 14. In embodiments where liner 44 is used, tube is positioned inside liner 44. As shown in FIGURE 1, in one embodiment, exit end 64 is positioned approximately at closed end 28 of well bore 14. Entry end 60 is positioned approximately at open end 16 of well bore 14. In one embodiment, coil tubing may be used as tube 58; however, any suitable tubing may be used as tube 58 (for example, jointed pipe).

In operation, a well bore, such as well bore 14, is formed in coal bed 30. In particular embodiments, well bore 14 is formed without forming a secondary well bore that intersects portion 22; however, a secondary well bore may be formed in other embodiments. Fluid injector 70 injects an injection fluid, such as water or natural gas, into entry end 60 of tube 58, as shown by an arrow 78. The injection fluid travels through tube 58 and is injected into closed end 28, as shown by an arrow 80. Because end 28 is closed, a flow of injection fluid is generated from end 28 to end 24 of portion 22 through gaps 104 and/or 102, as shown by arrows 84. In particular embodiments gap 104 may be blocked by a plug, packer, or valve 106 (or other suitable device) to prevent flow of fluid to the surface via gap 104 (which may be inefficient). In other embodiments, gap 104 may be removed due to the collapse of the coal against liner 44, as described in further detail below.

As the injection fluid flows through gaps 102 and 104, the injection fluid mixes with water, coal fines,

and resources, such as natural gas, that move into well bore 14 from coal bed 30. Thus, the flow of injection fluid removes water and coal fines in conjunction with the resources. The mixture of injection fluid, water, coal fines, and resources is collected at separator 74, as shown by arrow 88. Then separator 74 separates the resource from the injection fluid carrying the resource. Although the injection fluid may be used for some time to remove fluids from well bore 14, at some point (such as during the mid-life or late-life of the well) a pump may replace the use of the injection fluid to remove fluids from the well bore 14 in certain embodiments. The "mid-life" of the well may be the period during which well 14 transitions from high fine production to a much lower fine production. During this period, the coal may substantially stabilize around liner 44. In other embodiments, a pump may be used for the entire life of the well, although in such embodiments the particles in the well may not be swept out (or the extent of their removal may be diminished).

In one embodiment, the separated resource from separator 74 is sent to fluid injector 70 through tube 94 and injected back into entry end 60 of tube 58 to continue the flow of fluid from end 28 to ends 24 and 16. In another embodiment, liquid, such as water, may be injected into end 28 using fluid injector 70 and tube 58. Because liquid has a higher viscosity than air, liquid may pick up any potential obstructive material, such as coal fines in well bore 14, and remove such obstructive material from well bore 14. In another embodiment, air may be injected into end 28 using fluid injector 70 and

tube 58. In one embodiment, any combination of air, water, and/or gas that are provided from an outside source and/or recirculated from separator 74 may be injected back into entry end 60 of tube 58.

Respective cross sectional diameters 98 and 100 of liner 44 and tube 58 are such that gaps 102 and 104 are formed. As shown in FIGURE 1, the difference between diameter 40 and diameter 98 results in a formation of gap 102. The difference between diameter 98 and diameter 100 results in a formation of gap 104. The larger the gap, the more stress relief (and depth of penetration of the stress relief) that is provided in the coal. The size of gaps 102 and 104 may be controlled by adjusting diameters 40, 98, and 100. For example, portion 22 of well bore 14 may be formed so that diameter 44 is substantially larger than diameter 98 of liner 44. However, a smaller diameter 40 may be used where diameter 98 of liner 44 is smaller. Analogously, diameters 98 and 100 may be selected depending on the size of gap 104 that is desired. In one embodiment, diameter 98 is less than 4.5 inches; however, diameter 98 may be any suitable length. In one embodiment, diameter 100 is less than 2.5 inches; however, diameter 100 may be any suitable length. Diameter 98 may have any appropriate proportion with respect to diameter 40 to allow the desired amount of collapse. In particular embodiments, diameter 98 is less than approximately ninety percent of diameter 40. However, in other embodiments, diameter 98 may be very close to diameter 40 such that the coal is allowed to slightly expand against the liner (to relief stress) but does not disintegrate. Such an expansion of the coal

shall be included in the meaning of the term "collapse" or it variants.

Diameter 40 of portion 22 may be selected depending on the particular characteristics of coal beds 30. For example, where coal bed 30 has low permeability, diameter 40 of portion 22 may be larger for better resource production. Where coal bed 30 has high permeability, diameter 40 may be smaller. In particular embodiments, diameter 40 of portion 22 may be sufficiently large to allow portion 22 to collapse around liner 44. In one embodiment, diameter 40 of well bore 14 may be greater than six inches. In another embodiment, diameter 40 may be between approximately five to eight inches. In another embodiment, diameter 40 may be greater than 10 inches.

A collapse of well bore 14 around liner 44 may be advantageous in some embodiments because such a collapse increases the permeability of the portion of coal bed 30 immediately around liner 44, which allows more gas to move into portion 22 and thus improves the efficiency of resource production. This increase in permeability is due, at least in part, to the stress relief in the coal due to the collapse. The effects of this stress relief may extend many feet from well bore 14 (for example, in certain embodiments, up to fifty feet).

Furthermore, since the well bore 14 is allowed to collapse, the well bore 14 may be drilled in an "overbalanced" condition to prevent collapse during drilling without adversely affecting the flow capacity of well bore 14. Although overbalanced drilling does force drilling fluids (such as drilling mud) and fines into the

coal bed during drilling (which in some cases can reduce subsequent production from the coal), the "cake" formed around the wall of well bore 14 by the drilling fluid and fines deposited on the wall may be formed in a manner that is advantageous. More specifically, a thin cake may be formed by using a low-loss drilling fluid that minimizes fluid loss into the coal formation (for example, an invasion of drilling fluid and/or fines less than six inches into the coal seam may be preferable). Furthermore, the drilling may be performed and a type drilling fluid may be used such that the cake builds up quickly and remains intact during drilling. This may have the added advantage of supporting the coal to prevent its collapse before and while liner 44 is inserted.

In one embodiment, liner 44 is positioned in portion 22 without providing any support to prevent a collapse of portion 22, which increases the probability of well bore collapse. In such an embodiment, the probability of well bore collapse may be increased by drilling a well bore having a larger diameter than liner 44 and lowering the bottom hole pressure. Thus the coal may be collapsed onto the liner 44 by lowering the bottom hole pressure below a threshold at which the coal collapses. For example, the drilling fluid may be left in well bore 14 while liner 44 is inserted (to help prevent collapse), and then the drilling fluid (and possibly other fluids from the coal) may be pumped or gas lifted to the surface to instigate a collapse of the coal. The collapse may occur before or after production begins. The bottom hole pressure may be reduced either quickly or slowly,

depending, among other things, on the type of coal and whether the coal is to be collapsed or only expanded against liner 44.

In other embodiments, collapse of well bore 14 may instigated using any suitable methods, such as a transmission of shock waves to coal bed 30 using a seismic device or a controlled explosion. Allowing a collapse of or collapsing well bore 14 may be beneficial in situations where coal bed 30 has low permeability; however, coal bed 30 having other levels of permeability may also benefit from the collapse of portion 22.

FIGURE 2A is a cross sectional diagram illustrating one embodiment of liner 44 and tube 58 in well bore 14 at a location and orientation indicated by a reference number 108 in FIGURE 1. As shown in FIGURE 2A, injection fluid from fluid injector 70 flows in the direction indicated by arrow 80 (pointing towards the viewer). Because end 28 is closed, injection fluid is returned back to end 24 in a direction indicated by arrows 84 (pointing away from the viewer) through gaps 102 and/or 104. The flow of injection fluid in the direction indicated by arrow 84 creates a mixture of injection fluid, gas (resources), water, and coal fines that move into well bore 14 (as indicated by arrows 110). The mixture moves to separator 74 through opening 16.

FIGURE 2B is a cross sectional view of liner 44 and tube 58 in a collapsed well bore 14 at a location and orientation indicated by a reference number 108 in FIGURE 1. As shown in FIGURE 2B, in one embodiment, well bore 14 is allowed to close gap 102 by collapsing around liner 44 to increase the permeability of coal bed 30

immediately around liner 44 by relieving stress in the coal. Further, permeability may be increased through matrix shrinkage that occurs during the degassing of high gas content coals in coal bed 30. Thus, more gas moves from coal bed 30 into the space defined by liner 44 through apertures 54 of liner 44. Gas is then removed from well bore 14 using flow of fluid in the direction indicated by arrow 84 through gap 104. In one embodiment where liquid or other injection fluid having a viscosity level higher than that of natural gas or air is periodically injected into closed end 28 through tube 58, any coal fines 124 that may not have been removed before may be removed by the flow of injection liquid in direction 84.

FIGURE 3 is a flow chart illustrating one embodiment of a method 150 for removal of resources from well bore 14. Some or all acts associated with method 150 may be performed using system 12. Method 150 starts at step 154. At step 158, drainage well bore 14 having a drainage portion 22 is formed in coal bed 30. At step 160, liner 44 is positioned in well bore 22. In particular embodiments, step 160 may be omitted. At step 164, tube 58 is positioned in well bore 14. In embodiments where liner 44 is used, tube 58 is positioned within liner 44.

In embodiments where liner 44 is position in well bore 22 at step 160, well bore 22 may be allowed to collapse around liner 44 at step 168. In one embodiment, the collapse of well bore 22 may be instigated using any suitable method, such as a seismic device or a controlled explosion. At step 170, a flow of injection fluid is

generated from end 28 to end 24. In one embodiment, the flow may be generated by injecting injection fluid into closed end 28 of well bore 22 through tube 58; however, any other suitable methods may be used. The injection fluid may be any suitable gas or liquid. At step 174, a mixture that includes the injection fluid, resource, and water and/or coal fines is collected at the open end. At step 178, the mixture is separated into different components. In one embodiment, at step 180, a portion of the separated resource and/or water is injected back into closed end 28 of well bore 22 through tube 58. Alternatively, at step 180, injection fluid from an outside source may be injected back into closed end 28 of well bore 22 through tube 58 to continue the fluid flow. Steps 170 and/or 180 may be continuously performed to continue the fluid flow in well bore 22. Step 180 may be omitted in some embodiments. Method 150 stops at step 190.

In one embodiment, the injection fluid used to generate a flow of fluid may be natural gas or air. In one embodiment, the injection fluid may be liquid, such as water. Using liquid may be advantageous in some embodiments because liquid may be a better medium for coal fine removal.

Although embodiments of the present invention are only illustrated as being used in well bore 14, such embodiments may also be used in one or more lateral well bores drilled of well bore 14 or any other surface well bore. For example, one or more lateral well bores may extend horizontally from well bore 14 and a liner may be inserted through well bore 14 and into one or more of

these lateral well bores. The method described above may then be performed relative to such lateral well bores. For example, multiple lateral well bores may be successively cleaned out using such a method.

Although some embodiments of the present invention have been described in detail, various changes and modifications may be suggested to one skilled in the art. It is intended that the present invention encompass such changes and modifications as falling within the scope of the appended claims.